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-Technical Report-

Reduced Order Modeling for Rapid Simulations of Blast and Rollover Events of a Ground Vehicle and its Occupants Using Rigid Body Dynamic Models

Project Final Technical Report

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11 March 2013

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List of Symbols, Abbreviations, Acronyms

AoA	Analysis of Alternatives
ALE	Arbitrary Lagrangian Eulerian
APG	Aberdeen Proving Grounds, Maryland
ARL	Army Research Labs
ATD	Anthromorphic Test Device
ATEC	Army Test and Evaluation Center
CASSI	Concepts, Analytics, System Simulation and Integration
CONWEP	Conventional Weapons
CotS/COTS	Commercial-Off-the-Shelf
DoB/DOB	Depth of Burial
DoA	Department of the Army
DoD/DOD	Department of Defense
DRDC	Defense R&D Canada – Valcartier
EoS/EOS	Equation of State
FEA/FEM	Finite Element Analysis/Method
FSI	Fluid Structure Interaction
GHULL	Generic Hull (as in TARDEC Generic Hull)
HME	Home Made Explosives
IED	Improvised Explosive Device
JWL	Jones-Wilkins-Lee (as in Equation of state for explosives)
LFT&E	Live Fire Test and Evaluation
LS-DYNA	COTS structural dynamics software from Lawrence Livermore Software Corporation, CA
LS-PREPOST	COTS post-processing software from Lawrence Livermore Software Corporation, CA
M&S	Modeling & Simulation
MADYMO	MAthematical DYnamic MOdels
MPI	Message Passing Interface
NT-UBB	Near Term Underbody Blast program
POC	Point of Contact
PM	Program Management Office
PSM	Prescribed Structural Motion
R&D	Research & Development
RDECOM	Research, Development and Engineering Command
RHA	Rolled Homogeneous Armor (steel)
RO	Reduced Order (as in simulations)
SimBRS	Simulation-Based Reliability and Safety
SLAD	Survivability and Lethality Analysis Directorate
SPH	Smooth Particle Hydrodynamics
TARDEC	Tank Automotive Research, Development and Engineering Center
T&E	Test & Evaluation
UBM	Underbody Blast Modeling/Methodology
WD	Work Directive

Executive Summary

Due to the severity of forces exerted during an IED blast, ground vehicles undergo multiple sub-events including local structural deformation of the floor, blast-off, free flight and slam-down (including roll-over). The entire blast event from blast-off to slam-down may last as long as 2 seconds in duration depending on several parameters such as vehicle weight, charge size and location. Simulation of the entire blast event is computationally intensive due to the high fidelity levels of the model and the long duration of the event. The purpose of this project was to develop a computationally-efficient, reduced order model to simulate all these events in one single simulation. These reduced order models can be used for rapid evaluations of military ground vehicles due to short turn-around simulation times. Models were developed using MADYMO's rigid body and finite element integration techniques to simulate all critical sub-events a ground vehicle undergoes during a blast event from blast-off to slam-down. The report provides different methodogies used in MADYMO simulations, their performance results and comparisons.

Program Overview

The development and testing phases of this project were jointly executed by TASS-Americas, Livonia, MI (POC: Ms. Sherri Chandra). The R&D effort was supported by Contract W56HZV-08-C-0236 and funded as work directive WD0048 Rev 0 under the Simulation-Based Reliability and Safety (SimBRS) program. TARDEC provided the requirements, test examples, evaluation of the final models and overall technical monitoring and guidance to TASS over the course of the project (Technical POC: Mr. Jai Ramalingam)

The program started in October 2011 and was completed in November 2012. This R&D project was funded by the Underbody Modeling for Testing and Evaluation (UBM/T&E) project (Program Manager: Mr. Pat Horton, ARL/SLAD).

Summary of Accomplishments/Results

All the targeted tasks have been met, the most significant being:

- Three models with varying degrees of complexity and different loading methods have been demonstrated using MADYMO, for M&S of the entire blast event (from blastoff to slamdown). Which model to use will ultimately depend on several factors such as which aspects of the response are of importance, and the speed with which the analyses need to be turned around.

Recommendations

Evaluations should be continued to assess and improve this methodology in MADYMO.

- For ARL/SLAD's mission needs, MADYMO is well-suited for rapid simulations using rigid body dynamics, where numerous scenarios can be quickly analyzed.

- Future research in this area should include development and evaluation using more sophisticated loading methods in MADYMO such as the Particle Blast Method (from other projects such as Near Term Underbody Blast (NT-UBB) program).
- Ability of the current ATD model, and improved version of the same under development during the slamdown/rollover phase is unknown at this time and should be studied further.

Introduction

Improvised Explosive Devices (IEDs) pose a significant threat to military ground vehicles and soldiers in the field. Due to the severity of forces exerted by a blast, ground vehicles may undergo multiple sub-events subsequent to IED explosion including local structural deformation of the floor, blast-off and slam-down. Depending on the location of the IED under the vehicle, the vehicle may also be subjected to roll over. To understand injuries sustained by soldiers under all of various loading conditions, it is imperative to analyze the impact of each sub-event on soldier injuries. Using traditional finite element analysis techniques to evaluate an entire event is inefficient, as calculation times may exceed several days for one simulation of up to 300 milliseconds. Therefore, there is a need for a computationally efficient tool or methodology to simulate the entire blast event in faster turn around simulation time.

Scope/Purpose of Project

The main objective of this project was to develop a computationally efficient reduced order simulation model capable of analyzing end-to-end performance of military ground vehicles subjected to blast loading. This model will be used to determine the effects of blast loading on soldier injuries, including during the blast-off, potential rollover and slam-down phases.

Background Information

- MADYMO is a leading design and analysis software for occupant safety systems in the safety/crashworthiness industry. MADYMO is renowned for its fast and accurate calculations of injury risks and safety system performance, and for its accurate library of crash dummy and human body computer models.
- A sister project to this, involving the use of the explicit dynamics FEA solver, LS-DYNA for all 3 phases of the blast event, namely, Blastoff, Gravity Flight and Slam-down, has also been funded by the UBM/T&E project. That project is the subject of a different report.

Section 1: Methods, Assumptions and Procedures

The overall project execution of model development and analysis was divided into four major tasks outlined below:

Task 1: Development of vehicle Model

- Integrate a simplified ground vehicle model in MADYMO using combination of rigid body and finite element techniques equivalent to the LS-DYNA full finite element ground vehicle model .
- The integration shall consist of required geometric details of each component and sub-assembly of the vehicle, material properties of the structure and seats, and energy absorption characteristics of the seats.
- Select typical suspension and seat models, and integrate them into the MADYMO ground vehicle model.

Task 2: Integration of occupant and restraint systems

- Integrate a commercial 50^{th} percentile Hybrid III occupant model into the MADYMO ground vehicle model developed in Task 1.
- Route a standard seatbelt around the occupant model and connect it to vehicle anchor locations.

Task 3: Implementation of various blast loading methods

- Develop and implement different loadings methods in MADYMO to apply desired loading to the ground vehicle model structure from Task 2.
- Loading methods identified are:
  (a) Impulse based vertical loading into the vehicle

  (b) Prescribed accelerative vertical motion

  (c) Prescribed effective blast pressure map to the vehicle structure

Task 4: Analysis of vehicle and occupant results and comparisons of models

- Integrate the modified ground vehicle model from Task 2 with the loading method from Task 3 to develop a reduced order simulation model.
- Conduct an analysis to capture desired sub-events of floor deformation, vehicle rigid body response and occupant response during the blast-off phase, and vehicle/occupant response consisting of potential rollover during the slam-down phase.

Section 2: Development of Vehicle Model in MADYMO (Task 1)

LS-Dyna FE hull model converted to MADYMO

A MADYMO model of the hull was built to capture the geometric details and material properties of the FE hull model. An LS-Dyna full finite element model of the hull structure was converted to MADYMO using the TASS LS-Dyna to MADYMO Converter. All nodes and elements, materials and properties were converted. The parts and materials in the hull model, and their thicknesses, are shown in Fig.2.1.

Part	Material	Thickness
Main hull	RHA(rolled homogenous armor) Class 1 Steel	0.625"
False floor	ASTM Grade A36 steel	0.375"
Driver door	RHA(rolled homogenous armor) Class 2 Steel	0.625"
Driver door window	Glass	2"
UB Ribs	ASTM Grade A36 steel	2.5"
Hull Frame	ASTM Grade A36 steel	0.25"
Door hinges	RHA(rolled homogenous armor) Class 2 Steel	1.0"
Floor-rib bracket	ASTM Grade A36 steel	2.5"
Windshield	Glass	2"
Side-Top Window	Glass	2"
Rear Door	RHA(rolled homogenous armor) Class 2 Steel	0.625"
Hull Frame 2	ASTM Grade A36 steel	0.375"
Hull Roof	HSLA Grade 80 steel	0.375"

Figure 2.1 Hull Parts, Materials and Thicknesses

LS-Dyna material MAT_PIECEWISE_LINEAR_PLASTICITY for steel structures was converted to MATERIAL.ISOPLA in MADYMO. This material includes the properties of density, Young's Modulus, yield stress and Poisson's ratio. MAT_ELASTIC material for glass in LS-Dyna was converted to MATERIAL.ISOLIN in MADYMO. This material includes the properties of density, Young's Modulus and Poisson's ratio. The result of the conversion was a full FE model of the hull in MADYMO, shown in Figure 2.2.

LS-Dyna CONSTRAINED_NODAL_RIGID_BODY elements were converted to RIGID_ELEMENTs in MADYMO..MADYMO does not permit rigid elements to have common nodes as LS-Dyna does. Hence rigid elements with common nodes had to be fixed manually during the conversion process. Also, MADYMO does not allow nodes to be defined as a part of a rigid element and a part of a supported

element at the same time, so rigid elements in parts of the model that are defined as supported facet elements had to be removed.

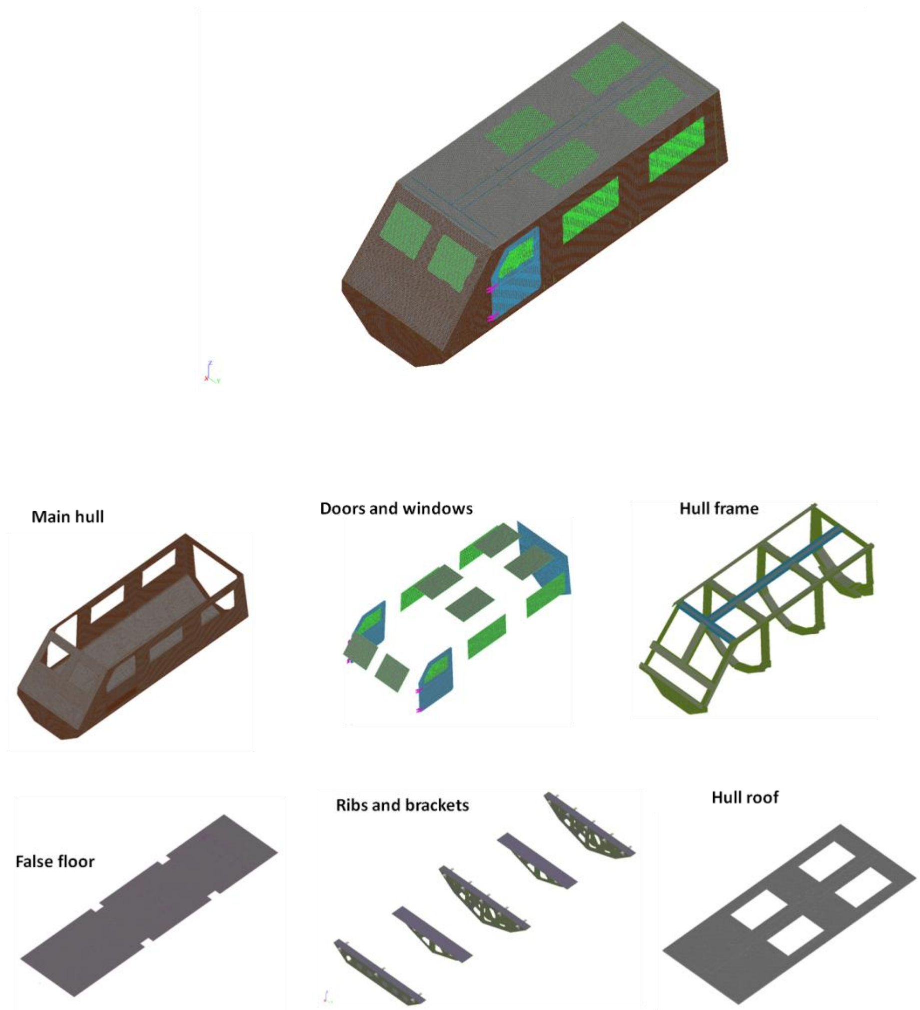


Figure 2.2 Hull full FE model in MADYMO

Simplified models

Based on the full finite element vehicle model converted to MADYMO, three simplified vehicle models were created using 1) planes, 2) rigid facets, and 3) a combination of rigid facets and deformable finite elements.

Planes

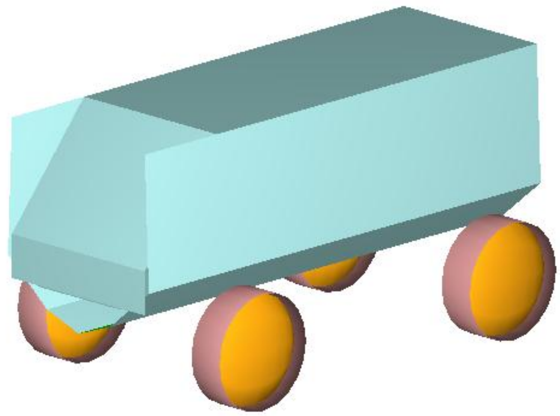


Figure 2.3 Plane Vehicle Model

The purpose of this step was to create an efficient model with reduced runtime which captures the important information from the detailed FE model for the motion of the vehicle during the blast-off and slam-down phases. A zero time MADYMO run of the finite element hull model calculated the mass, center of gravity and moments of inertia of the hull. These values were assigned to a vehicle rigid body in the MADYMO plane model, shown in Figure 2.3. The basic hull geometry was defined by planes, rigidly attached to the vehicle body. The hull was defined using non-deformable null materials. The density, Young's modulus and Poisson's ratio were taken from the finite element model and assigned as contact properties for the multi-body model to be used for contact stiffness calculations. The planes model would be the fastest running since the total degrees of freedom and contacts are highly simplified. However the model would also only represent limited structural and geometric details.

Facet

The purpose of this step was to create an efficient model with reduced run time which captures the important information from the detailed FE model for the motion of the vehicle during the blast-off and slam-down phases and can be used for contacts of the vehicle with the ground on rollover. Facets are used instead of planes to allow contact of the vehicle with the ground plane due to possible rollover and slam-down. While the geometric details of the vehicle are well represented for interface or contacts, local hull and floor deformations would not be captured in simulations. This model is shown in Figure 2.4

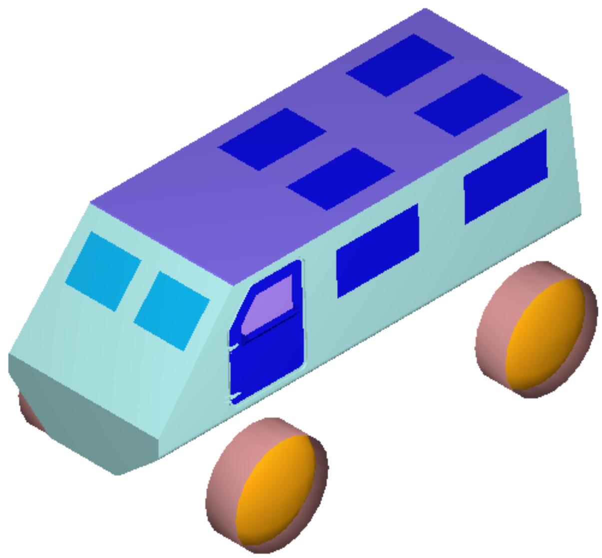


Figure 2.4 Facet Vehicle Model

Combined Facet and FE

The purpose of this step was to create a model which would capture the deformation of the hull due to the blast pressure load, as well as the vehicle rigid body motion. To do this as efficiently as possible, a combination of facet and finite elements were used. The parts that deform due to the blast force were made of deformable finite elements and the rest of the parts were made of rigid facet elements. To further reduce required CPU times, the deformable parts would be switched to rigid after the simulation ran for 30 msec. The main hull was split into two parts – rigid walls and deformable floor, as shown in Figure 2.5

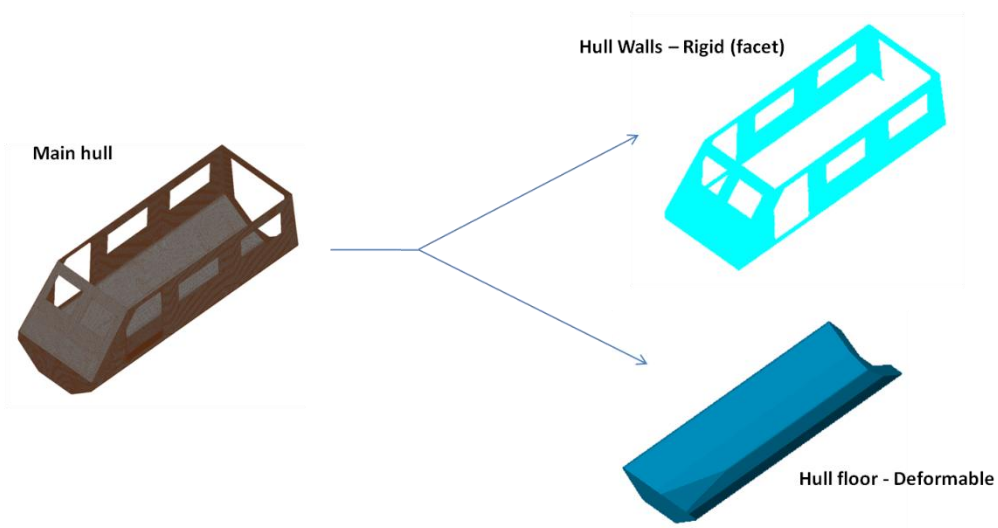


Figure 2.5 Main Hull split into Rigid and Deformable Parts

The deformable parts of the FE model are then the hull floor, hull frame, false floor, UB ribs and floor-rib brackets, as shown in Figure 2.6

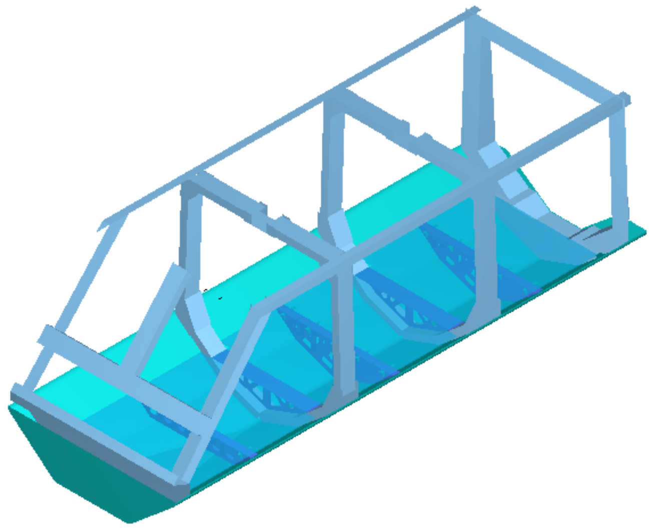


Figure 2.6 Deformable parts of FE model

Suspension and stroking seat models

MADYMO models of the suspension, using joints, and the tires, using rigid bodies, ellipsoids and cylinders, were developed and integrated with the vehicle hull model. Tire dimensions used in this model were (from Michelin 335/80R20): diameter – 40.7”, tread width – 338 mm, and tire weight – 106 lb. At the center of each tire there are three joints. The support joint is a bracket joint with zero degrees of freedom which connects the support body to the vehicle body. The suspension joint is a translational joint with one degree of freedom, which is translation along the z-axis. This joint connects the suspension body to the support body. The wheel joint connects the tire body to the suspension body with a universal joint with two degrees of freedom, which are rotation about the y-axis and bending about the x-axis. This is shown in Fig. 2.7

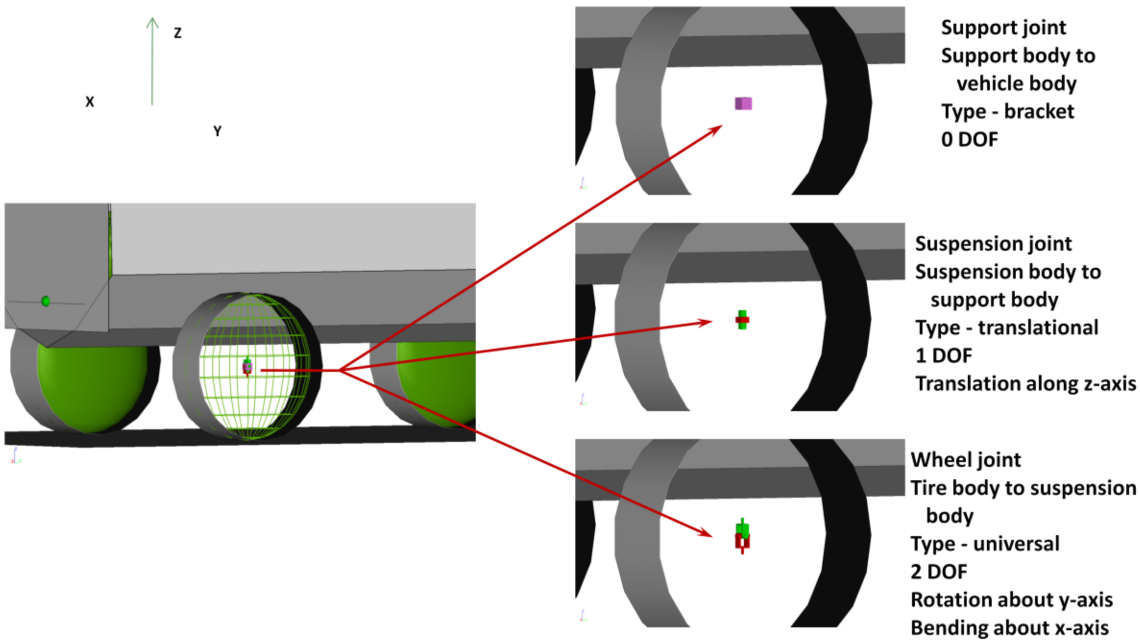


Figure 2.7 Suspension joints

A suspension spring model which allows reasonable stroke of the suspension was used. The function is shown in Figure 2.8

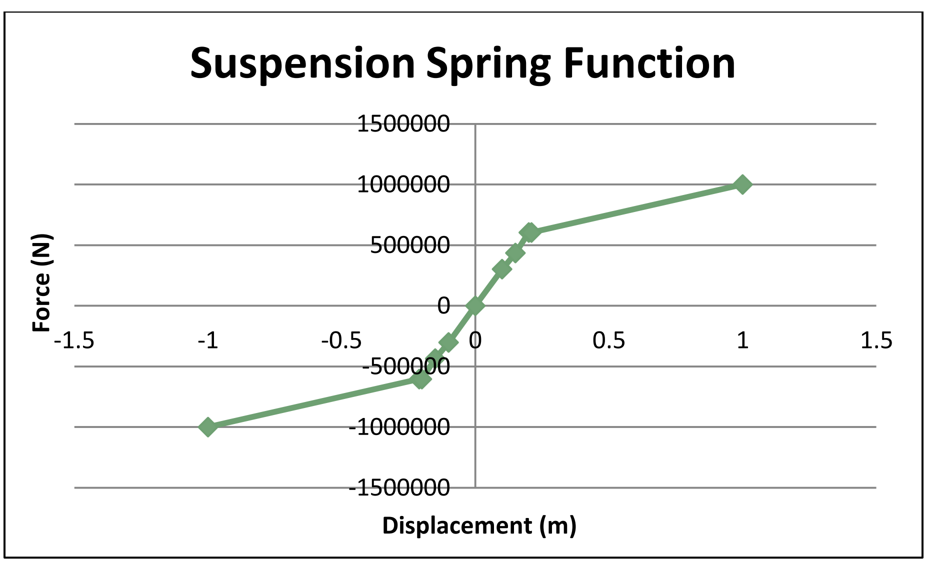


Figure 2.8 Suspension Spring Function (generic)

A joint restraint which prevents bending of the wheels about the y-axis was used. This can be modified by users of the model if some bending is desired. The function is shown in Figure 2.9

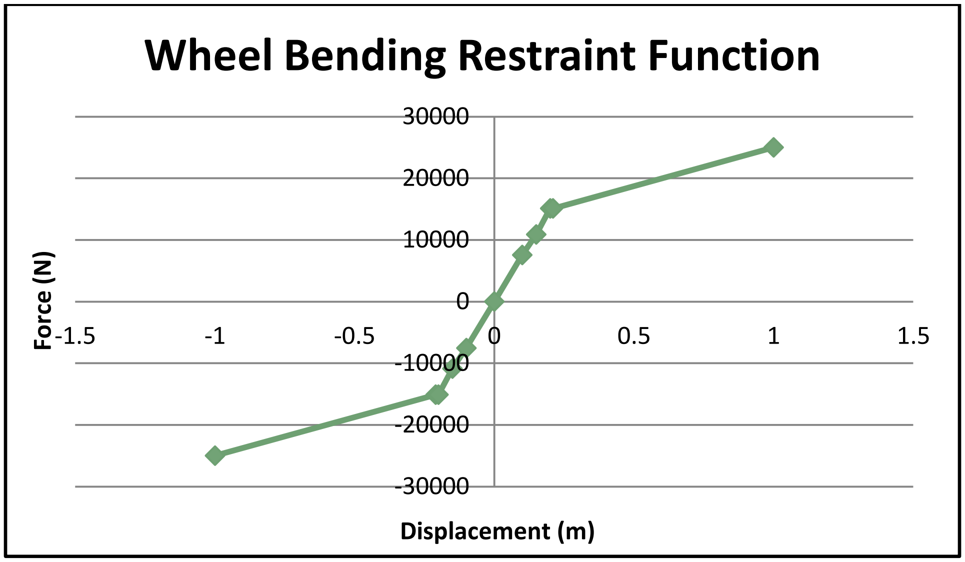


Figure 2.9 Wheel Bending Restraint Function (generic)

A generic model of a stroking seat was built, shown in Figure 2.10, with the energy absorbing function shown in Figure 2.11. Contact forces for interaction with the dummy are based on standard dummy stiffness characteristics. Stroking of the seat is limited by contact of the seat bottom cushion ellipsoid to the seat stop plane. The position of the seat stop plane was adjusted to limit stroke to approximately 6 inches.

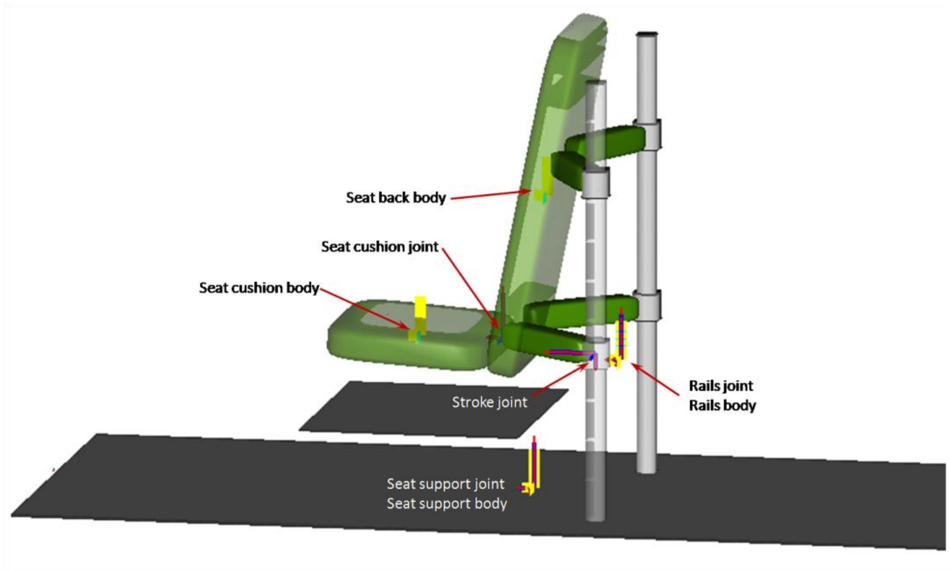


Figure 2.10 Stroking Seat Model (generic)

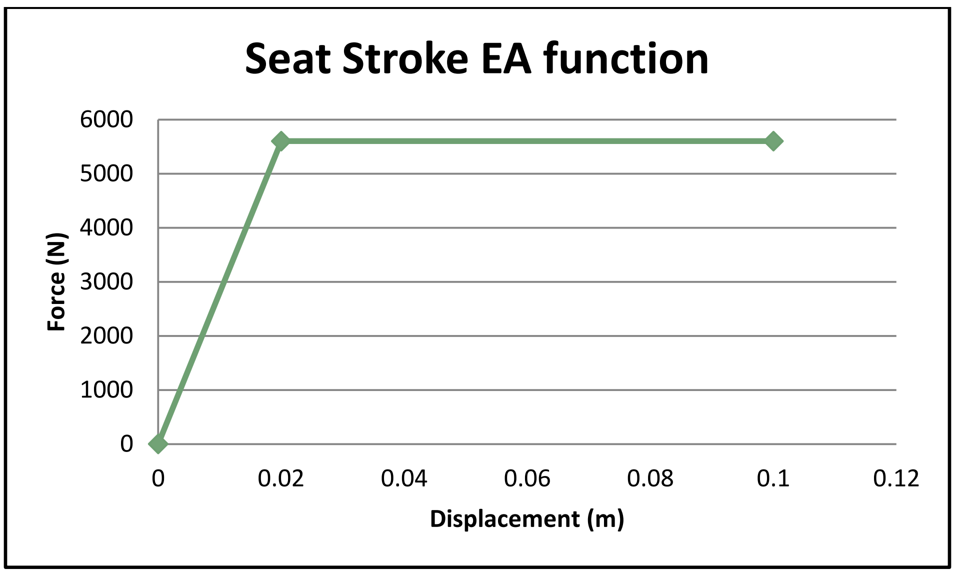


Figure 2.11 Stroking Seat EA Function (generic)

Section 3: Integration of Occupant and Restraint Systems (Task 2)

A 50^{th} %-ile Hybrid III male dummy model was added to the MADYMO model. Occupant positioning data was not specified, so the dummy model was placed in a seat in the center front part of the vehicle. The position of the seat and the dummy can be adjusted when this information is available. A 4-point harness system including lap and shoulder beltsand center buckle was positioned on the dummy, as shown in Figure 3.1

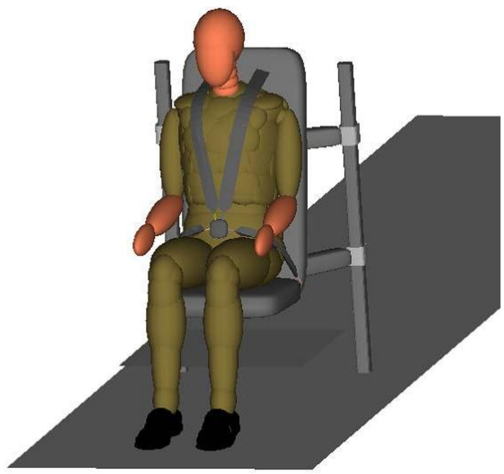


Figure 3.1 Dummy and Harness System Setup

Seatbelts were modeled with 2-dimensional finite element parts and 1-dimensional multi-body parts, with a generic stiffness. The stiffness of the 1D parts was calculated by multiplying the stiffness of the FE parts by the area of the cross-section of the belt material. The FE portions of the belt are in contact with the dummy, and the MB parts connect the ends of the FE belts to the buckle and the anchor points. The stiffness functions for FE and 1D belts are shown in Figure 3.2 and Figure 3.3.

Occupant response output was requested for the following injuries: lower and upper tibia forces, head, chest and pelvis accelerations, lumbar spine load and upper neck load.

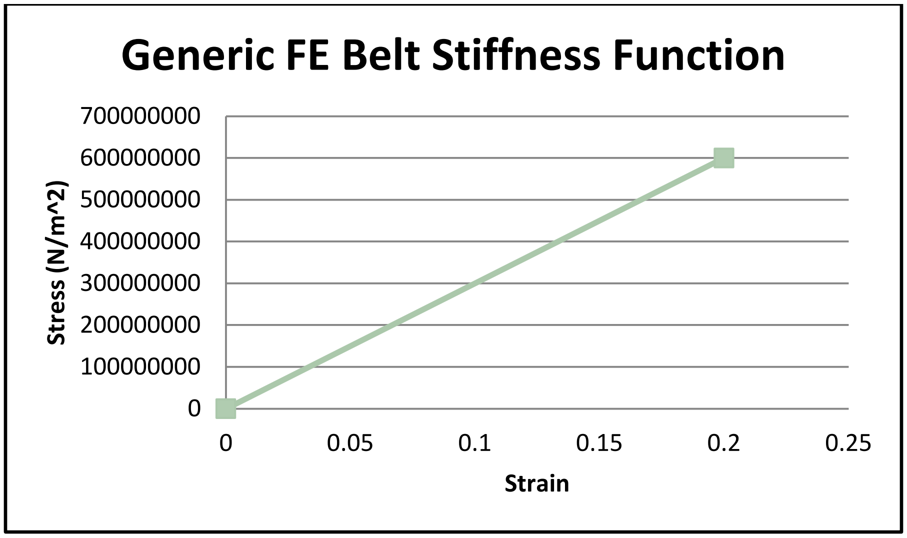


Figure 3.2 FE Belt Stress-Strain Function

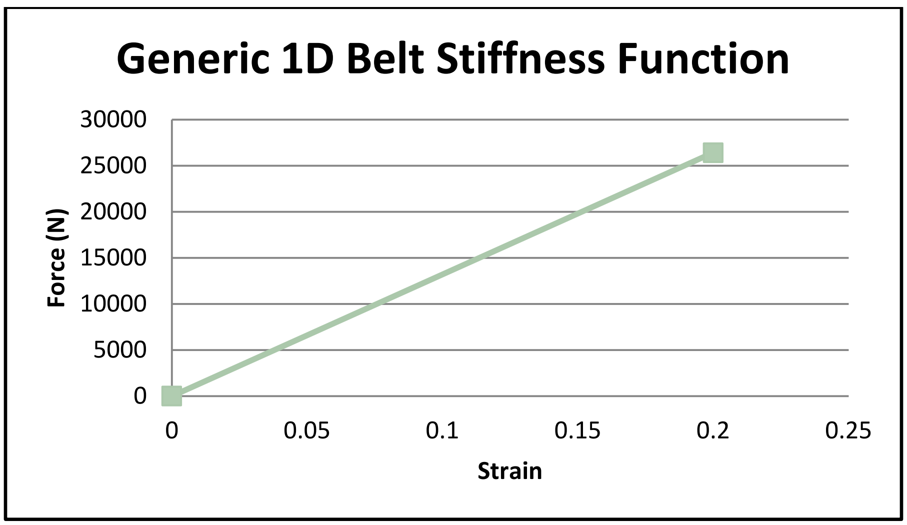


Figure 3.3 1D Belt Force-Deflection Function

Section 4: Implementation of Different Blast Loading Methods (Task 3)

Several different methods were attempted to model the blast loading on the vehicle and the occupant.

Simple Pulse based vertical loading

Acceleration pulse

A vertical acceleration pulse was applied to the vehicle rigid body. The sample pulse has a maximum acceleration approximately 180 g's, as shown in Figure 4.1. When the model ran with this applied acceleration, the motion of the vehicle was not changed when the mass of the vehicle was changed. Another limitation of this loading method would be the need to include the effect of gravity in the prescribed motion pulse to generate the vehicle free flight and return to ground events.

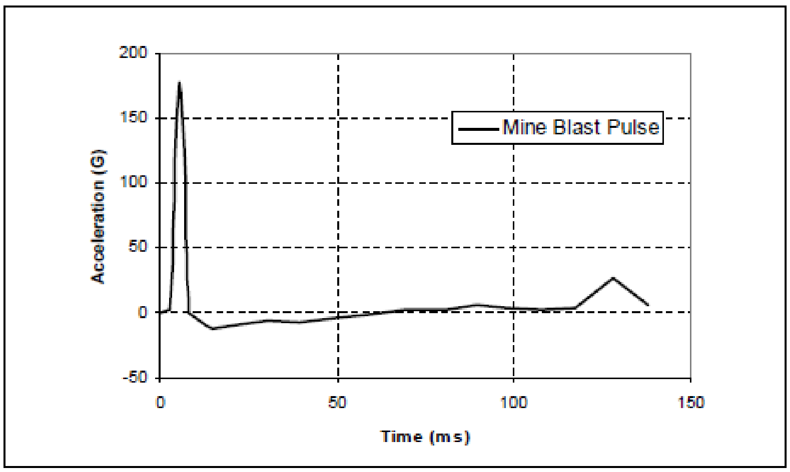


Figure 4.1 Mine Blast Acceleration Pulse

Source: "Reduction of Acceleration Induced Injuries from Mine Blasts under Infantry Vehicles", by Ala Tabiei and GauravNilakantan
http://www.dynalook.com/european-conf-2007/reduction-of-acceleration-induced-injuries-from.pdf

Actuator load

Due to the limitation of acceleration pulse based loading method, a force (or impulse) based loading method was developed. In this method, instead of prescribing the vehicle motion through acceleration pulse, a force profile (time-history) would be applied to the vehicle. For example, a force based on the 180 g acceleration pulse was generated by multiplying the acceleration by the mass of the vehicle, as shown in Figure 4.2. Another advantage of this method is that the force can be applied on any specified location of the vehicle.

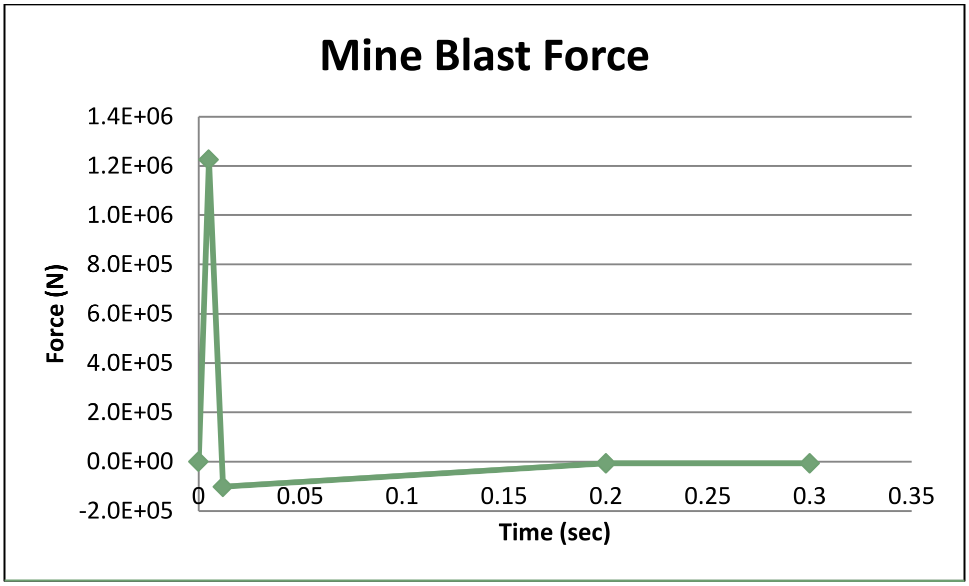


Figure 4.2 Mine Blast Force

This type of blast loading method was simulated by applying an actuator load in MADYMO, first to the center of gravity of the vehicle, causing blast-off and slam-down. Next a load was applied to the center of the hull side edge, causing blast-off, partial rollover and slam-down. Finally, a load was applied to the lower front corner of the vehicle, which also caused lift-off, partial roll-over and slam-down. These load application points are shown in Figure 4.3, and the results of the vehicle kinematics during the full event, with the load applied to the lower front corner of the vehicle, are shown in Figure 4.3

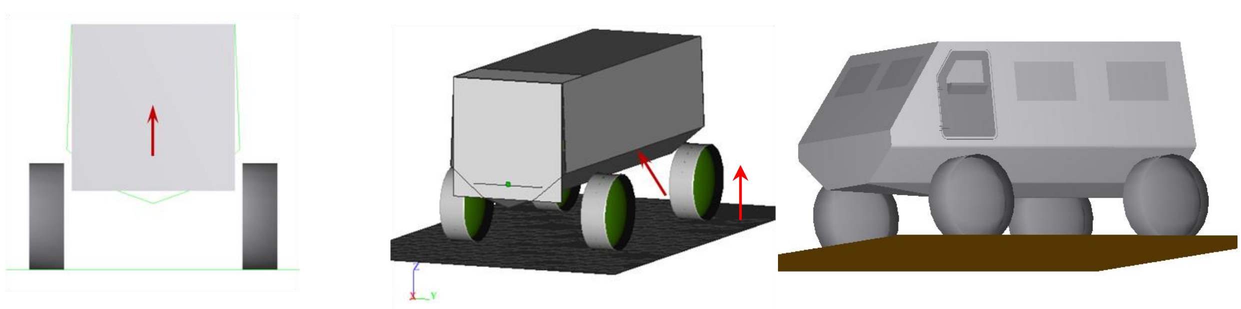


Figure 4.3 Actuator Load Points of Application; Resulting vehicle kinematics predicted by MADYMO (next page)

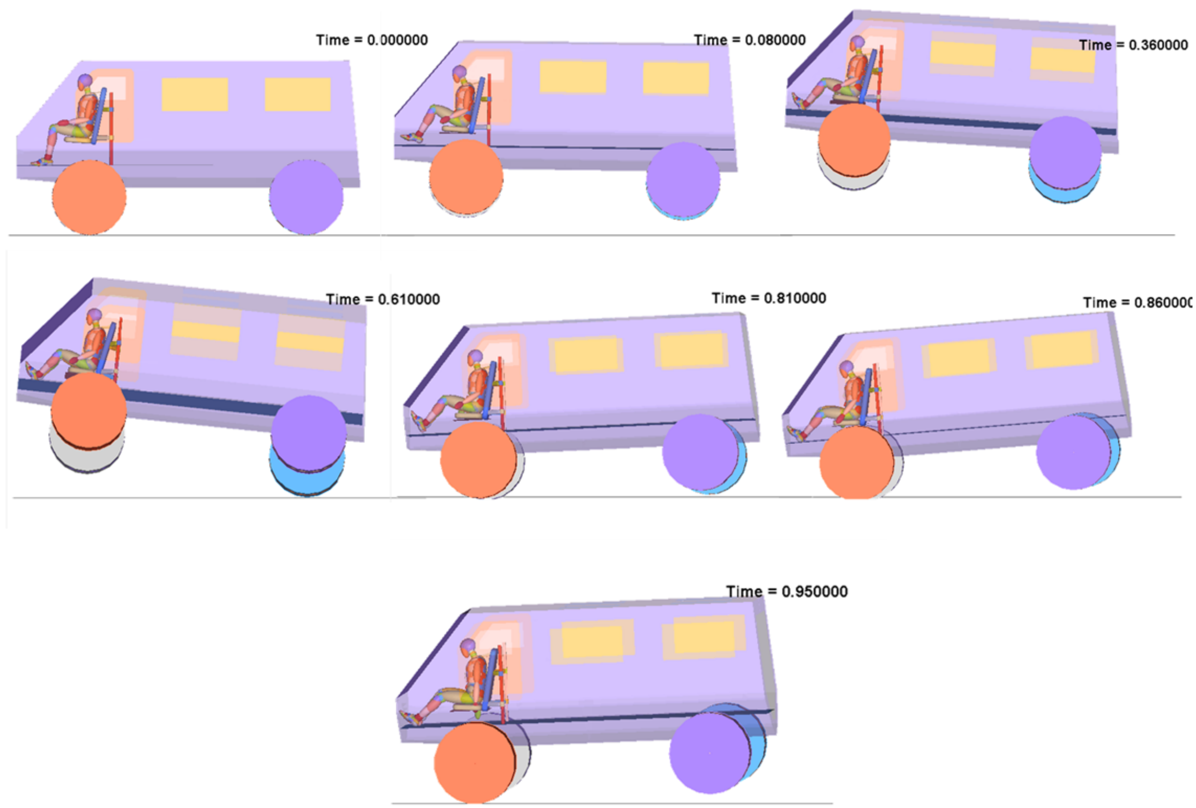


Figure 4.3a Vehicle Kinematics during the entire blast event

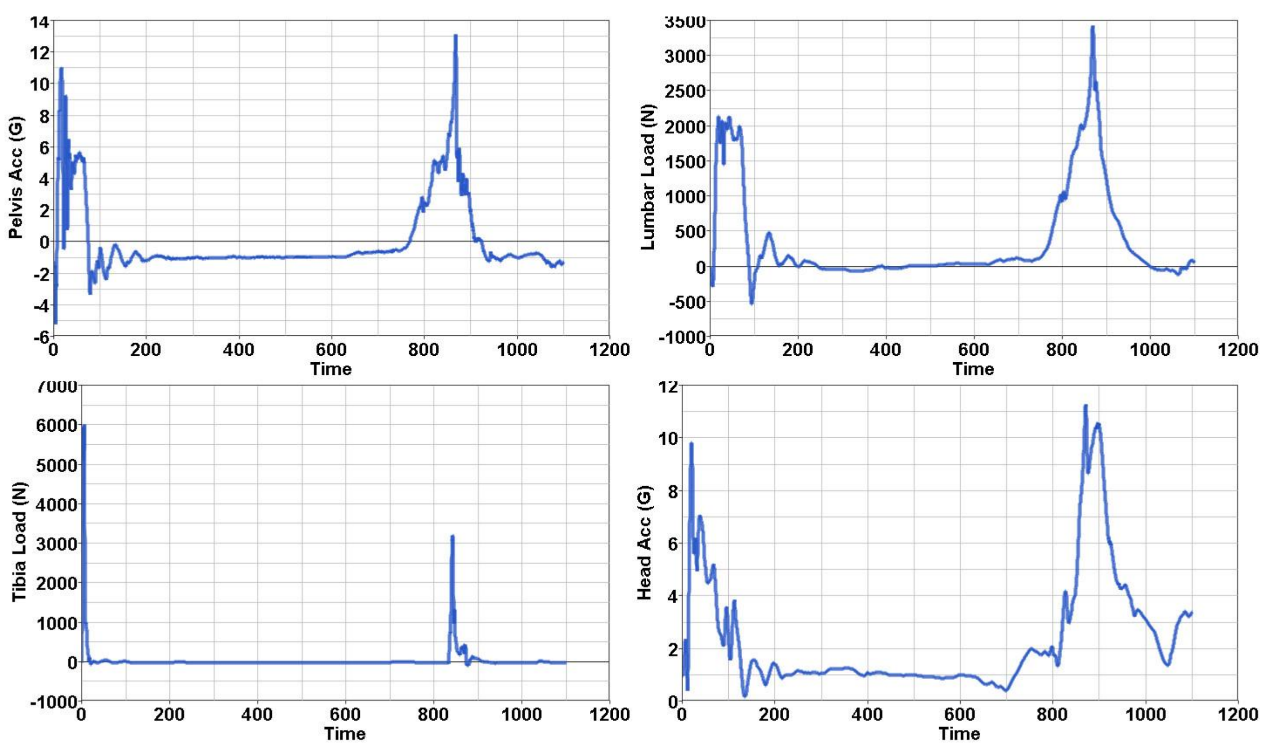


Figure 4.3b Injury responses during the entire blast event. 0-100 ms (blastoff), 800-1000 ms (slamdown)

Prescribed accelerative vertical motion / PSM

Prescribed structural motion was used to model the deformation of the hull due to blast. An LS-Dyna model which included the ConWep function was run, with a charge mass corresponding to a Level 4 STANAG threat, located approximately 0.26 meters below the hull of the vehicle, as shown in Figure 4.4

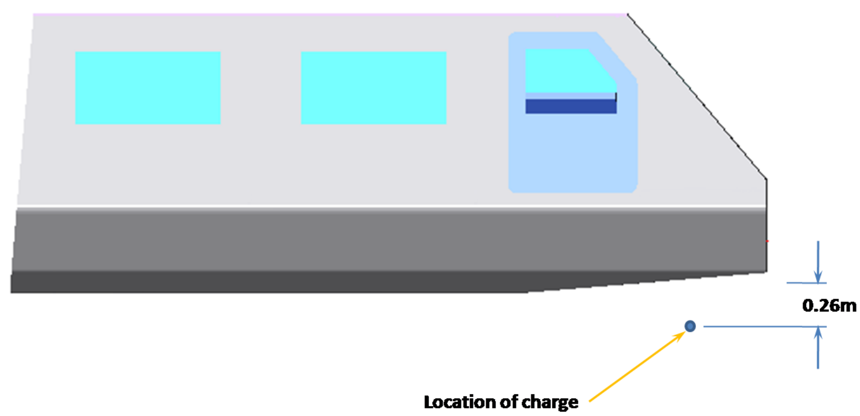


Figure 4.4 Charge location

The blast load from ConWep caused deformation of the hull floor structure, underbody ribs, hull frame, false floor and floor-rib brackets. The blast force interface pressure contours output by LS-Dyna are shown in Figure 4.5. The deformation of the hull floor and false floor were captured in a prescribed structural motion (PSM) file to be input to MADYMO. The deformation of the hull floor in MADYMO is shown in Figure 4.6. PSM captures the deformation of the structure in the model, but it does not allow the deformed parts of the model to move with the whole vehicle when the vehicle moves due to the blast. In other words, PSM method when applied to partial structural content of the vehicle could represent the local deformations of the vehicle structure however can not transfer the vehicle global motion along with local deformations. Modifying the PSM method so that it could capture both the deformation and gross motion of the vehicle, though possible, would be a complicated and time-consuming process.

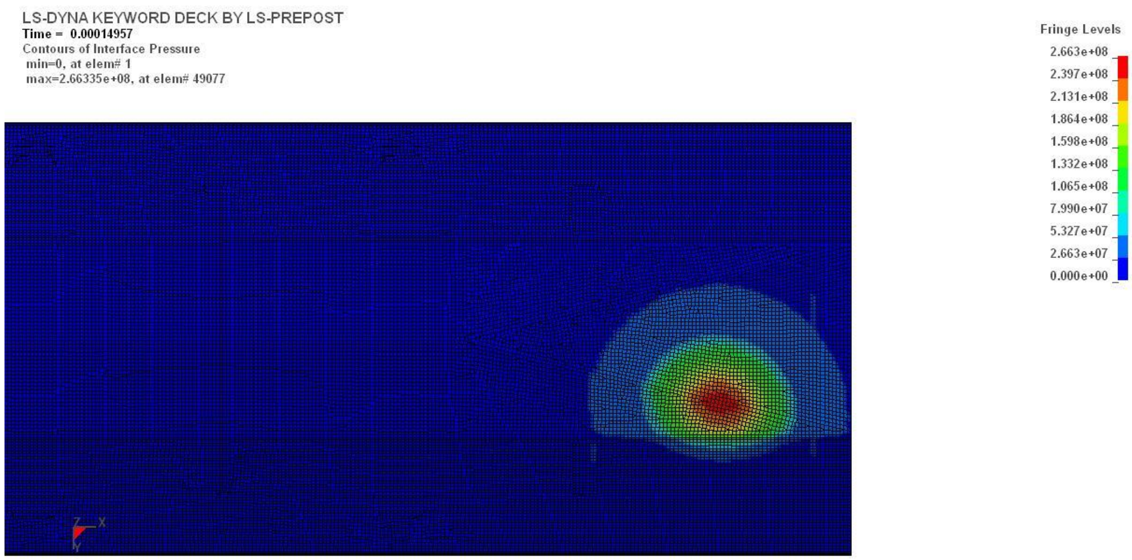


Figure 4.5 Contours of Interface Pressure from Blast

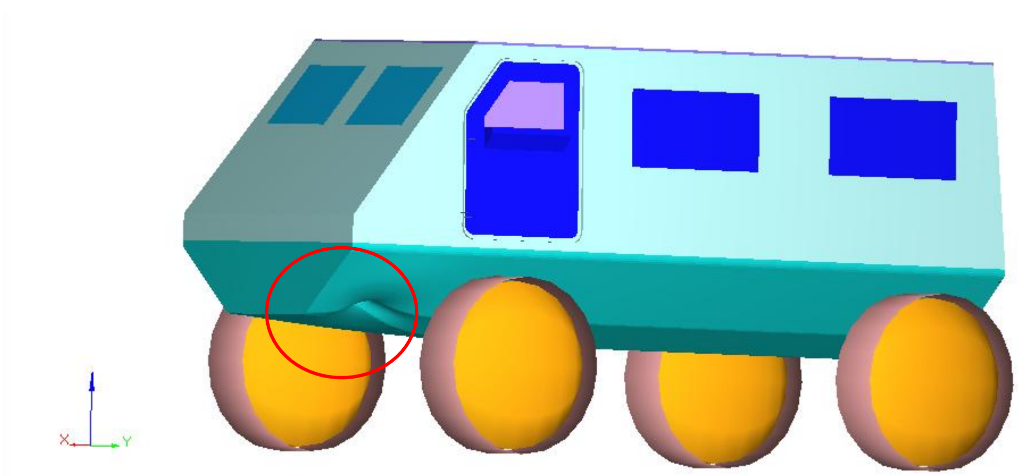
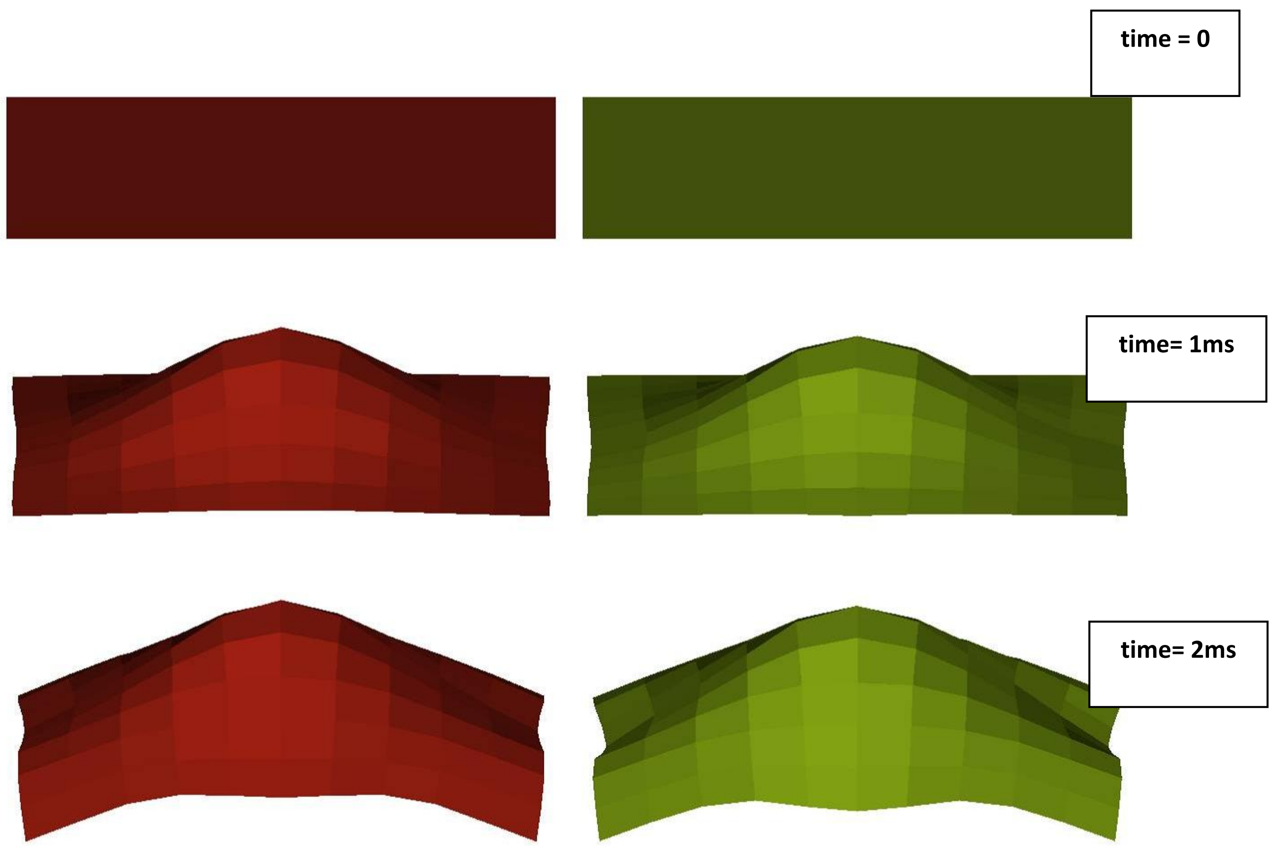


Figure 4.6 Deformation of hull due to blast

Blast pressure

In the pulse based loading methods that were developed thus far, an aggregate load was applied to a single point on the rigid vehicle. However, in order to capture local deformations of the hull along with global motion of the vehicle, a blast pressure based loading method was developed. In this method, basically pressure profile from a blast event would be applied on the underbody hull surface shell elements. For this project, the blast pressure profile was obtained from Conwep simulation in LS-Dyna.

In MADYMO, there are two ways to apply the pressure data on the structure: 1) through nodal forces or 2) pressures on element faces. Hence in this project, both nodal forces and pressure on elements were investigated as a way to model the effects of the blast on vehicle hull deformation and vehicle rigid body motion.A simple plate model was used to test this loading method and also to determine the best way to apply pressure. A blast load was applied in LS-Dyna using ConWep, producing deformation of the plate and motion of the plate as a whole. Outputs from the LS-Dyna model included nodal forces (NODFOR) and blast pressure (BLSTFOR). In MADYMO, nodal forces can be modeled using LOAD.NODE cards, and pressure can be modeled using LOAD.PRES cards. Each were tried to see if either could be used to simulate the blast in MADYMO. Kinematics from the simulations using each of these methods were compared to the LS-Dyna model output. The nodal forces produced much less deformation and motion of the plate, while element pressures produced similar results to LS-Dyna. Figure 4.7 shows a comparison of plate deformation and motion from LS-Dyna and MADYMO using pressure on the elements. Based on this plate simulation results, applying pressure on elements, as a pressure vs time curve was selected for full vehicle simulation.



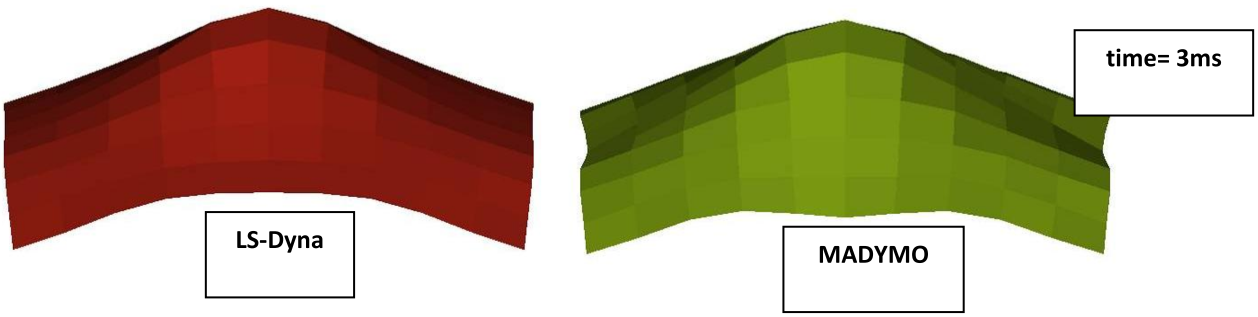


Figure 4.7 Plate Kinematics Comparison from LS-Dyna and MADYMO

A Python script was written to convert pressure vs. time curves from LS-DYNA output file BLSTFOR applied to segments, to MADYMO input format applied to the corresponding elements. Because LS-Dyna outputs pressure on segments rather than elements, the script had to find the elements in the input which correspond to the segments in the output and apply the output pressure to the corresponding elements, as shown in Figure 4.8. It was also noted during the script development that, depending on the grid size and volume of data to be processed, care should be taken to select only hull elements that are near the charge and would be subjected to non-negligible blast pressure loads. The script runs prohibitively long if too many elements are chosen on which to apply the pressure. If the time efficiency of the script can be improved in the future, more nodes/elements can be chosen for pressure application, and the deformation and motion of the vehicle can be modeled more precisely.

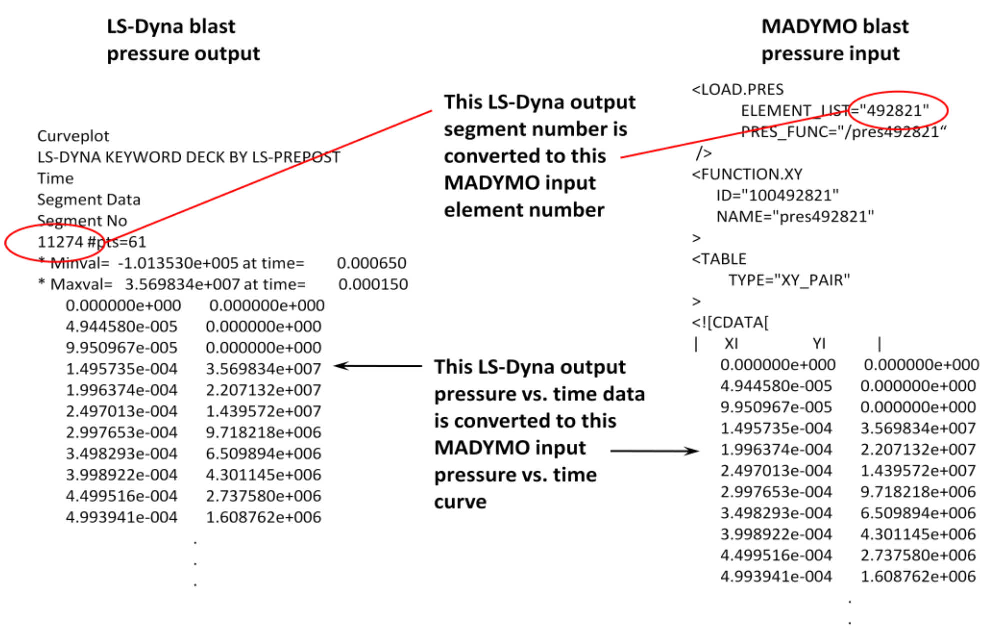


Figure 4.8 Script Example Input and Output

The script accomplishes its purpose with the following steps:

1. Reads nodal coordinate data from the original LS-Dyna input keyword file.
2. Reads nodal coordinate data from a keyword file based on the LS-Dyna pressure output.
3. Finds matching coordinates in the two files and changes the node numbers in the output file to the node numbers from the matching nodal coordinates in the input file.
4. Changes the node numbers in the element data of the output file to the node numbers with the matching coordinates.
5. Reads element data from the original LS-Dyna input file.
6. Finds elements in the input file with matching nodes in the output file and changes the elements numbers in the output file to the matching element numbers from the input file.
7. Changes the segment numbers on which the pressure is applied in the blast force pressure output file to the corresponding element numbers from the input file.
8. Outputs the element pressure vs. time curves for the correct elements in MADYMO format.

This process is illustrated in the flowchart in Figure 4.9.

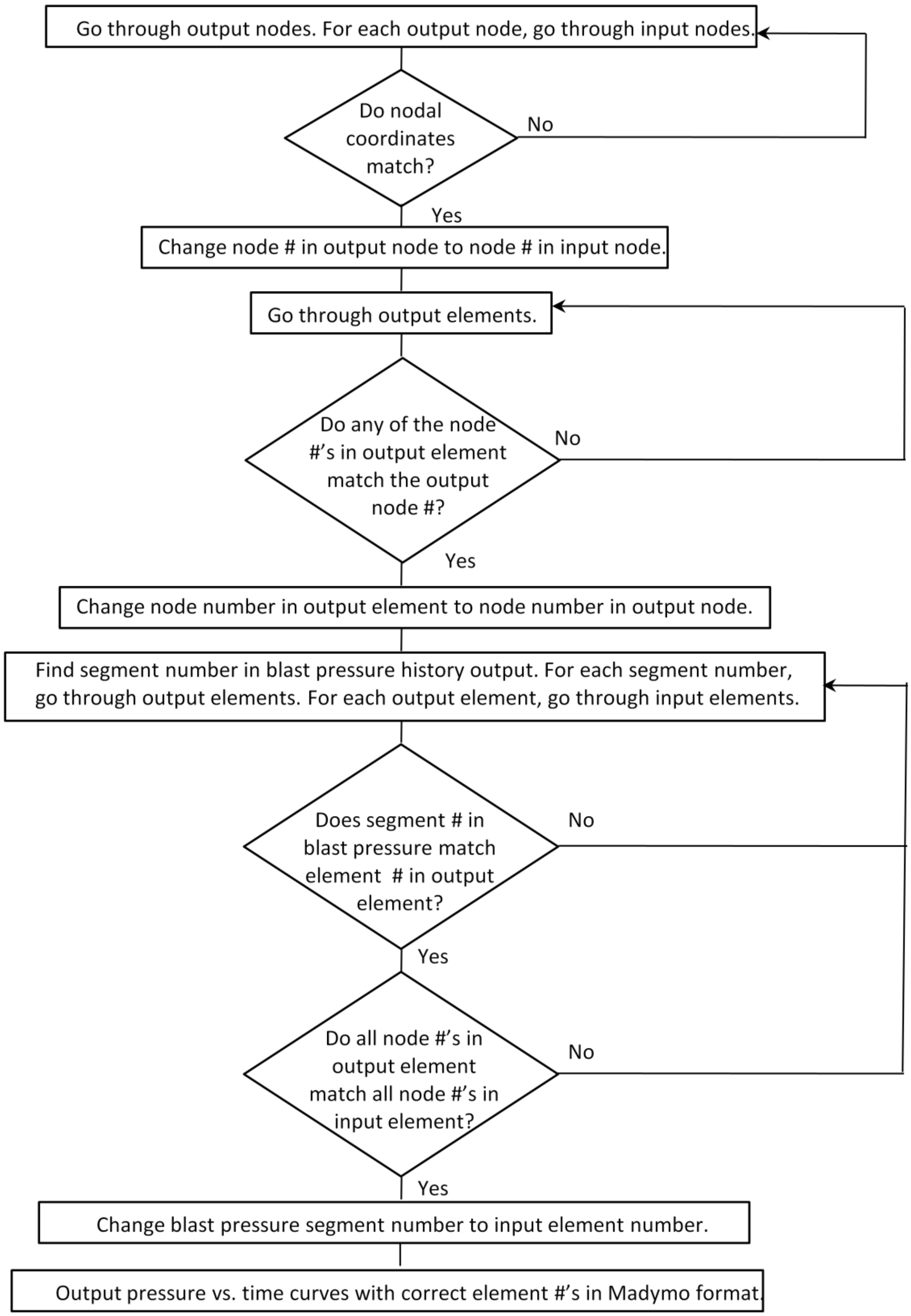


Figure 4.9 Script flowchart

The pressure vs. time curves resulting from the script were used as input to MADYMO with an include file.

Section 5: Analysis and Comparison of Simulation results (Task 4)

Three different model types were integrated with two different loading methods to develop reduced order simulation models, as shown in Figure 5.1.

Model Type		Loading Method	
		Impulse based loading	Blast pressure from LS-Dyna
All Rigid Vehicle	Planes	X	
	Facets	X	
All Rigid Upper Vehicle *and* Deformable Lower Vehicle	Rigid - facet Deformable - FE		X

Figure 5.1 MADYMO models

Model 1: Plane model with impulse based loading

The first model used planes to model the vehicle structure, and used actuator load to model the blast load. This model was used to model blast-off and slam-down when the load was applied to the center of gravity of the vehicle. A second load application point with this model, at the center side of the vehicle, was used to model blast-off, partial roll-over and slam-down.

Model 2: Facet model with impulse based loading

This model used rigid facet elements to model the vehicle structure, and used actuator load to model the blast load. This model was used to model blast-off, slam-down and partial roll-over. Facets were used in this case instead of planes in order to model the potential contact of the vehicle walls to the ground.

Model 3: FE/Facet model with blast pressure loading

The third model used rigid facet elements to model the upper vehicle structure and deformable finite elements to model the lower vehicle structure. The vehicle hull floor, false floor, UB ribs, hull frame and floor-rib brackets were deformable for the first 30msec of the MADYMO simulation. After 30 msec,

when the deformation is complete, a switch was used to turn the deformable parts to rigid, to reduce computation time. The load was modeled using blast pressure applied to elements, using LOAD.PRES in MADYMO.

As a check on the validity of the multi-body models, actuator load (check the number) was applied at the same location on both the plane model and the facet model to determine if there would be any difference in the results. The results for both simulations were the same.

Model evaluation/comparison

A comparison of run times for all of the models is shown in Figure 5.2. All models were run on 2 CPU on Linux Centos 6.X. The FE/facet model was also run using 4 CPUs and 8 CPUs to determine the speed-up possible with more CPUs. A 19% speed-up was obtained by using 4 CPUs, and a 45% speed-up was obtained by using 8 CPUs.

Model	Jump	Roll1	Roll2	Pressure		
Model Type	MB - plane	MB - plane	MB - facet	FE/Facet		
Elapsed time to run model for 500 msec	8 min, 41 sec	9 min, 4 sec	1 hour, 12 min	2 CPUs - 18 hr, 48 min	4 CPUs - 15 hr, 15 min	8 CPUs - 10 hr, 24 min

Figure 5.2 CPU time comparison

The rigid body models provide quick run times, and work well for modeling the overall vehicle motion. However, they cannot simulate the deformation of the hull and false floor due to the blast load. The occupant response from these models does not include the effects of the contact of the deforming false floor with the occupant's feet. Occupant injuries are due only to the acceleration of the vehicle and contacts of the dummy with vehicle interior surfaces, seat and harness system due to the motion of the vehicle.

The finite element/facet model has longer run times, but can be used to model both deformation of the vehicle hull structure and gross vehicle motion. Occupant injuries in this model include the effect of the false floor deformation on the tibia loading as well as the effect of vehicle acceleration and interior contacts.

Injury numbers for the various models are shown in Figure 5.3. These are preliminary numbers, based on generic seat properties and assumed dummy position, which can be modified for different vehicle configurations. These occupant injury numbers can be used to show trends for the various models. For example, for the blast pressure model with the given charge mass, the head, chest and pelvis accelerations are relatively low. The tibia forces are high due to the deformation of the false floor, which

contacts the feet, applying force. On the other hand, for the second jump and roll model, which simulates blast-off, partial rollover and slam-down, the head, chest and pelvis accelerations are high due to the acceleration of the vehicle.

Hybrid III 50th	Unit	Jump	Jump & Roll 1	Jump & Roll 2	Blast force pressure
Head Res Accn	g	77	46	261	13
Chest Res Accn	g	65	46	304	13
Pelvis Res Accn	g	76	86	334	37
Tibia Upr Left Z Force	N	7084	2834	21471	26512
Tibia Lwr Left Z Force	N	10979	4368	33557	41243
Tibia Upr Rt Z Force	N	7126	1967	19714	13336
Tibia Lwr Rt Z Force	N	11048	3015	30823	20702
Lumbar Spine Z Force	N	18197	10730	48476	2954
Upper Neck Z Force	N	3232	1935	10776	513

Figure 5.3 Preliminary injury results

Kinematic Comparison between MADYMO and LS-Dyna models

An LS-Dyna model with ConWep blast force applied to all segments of the hull floor and a MADYMO model with PSM (prescribed structural motion) for all nodes of the vehicle were both run for 50 msec. Then deformation of the hull and motion of the vehicle were compared. Applying PSM to ALL the nodes in the MADYMO model produced the same kinematics of the vehicle, both for deformation and motion, as in the LS-Dyna model. However, extracting structural motion of all the finite element nodes in the vehicle and importing is neither feasible nor valid as the entire finite element part of the MADYMO model will behave as a rigid body at any instance. Furthermore, PSM needs to be input for the entire simulation event, blast-off to slam-down, which means the LS-dyna full system simulation also needs to be run for the entire event.

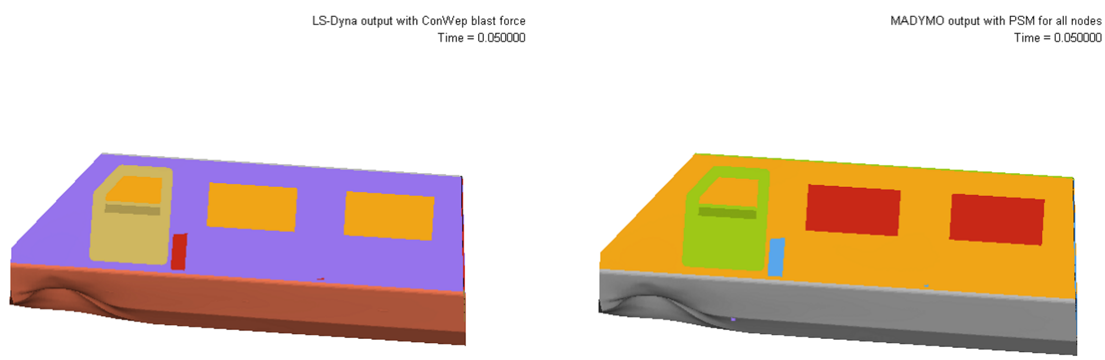


Figure 5.4 Kinematics at 50 msec for LS-Dyna output with ConWep blast force, and MADYMO output with PSM for all nodes

An LS-Dyna model with ConWep blast force applied to some segments in the hull floor and a MADYMO model with pressure from script applied to the same elements were both run for 50 msec. Again, deformation of the hull and motion of the vehicle were compared. The MADYMO model with pressure input produced the same kinematics of the vehicle, both for deformation and motion, as in the LS-Dyna model.

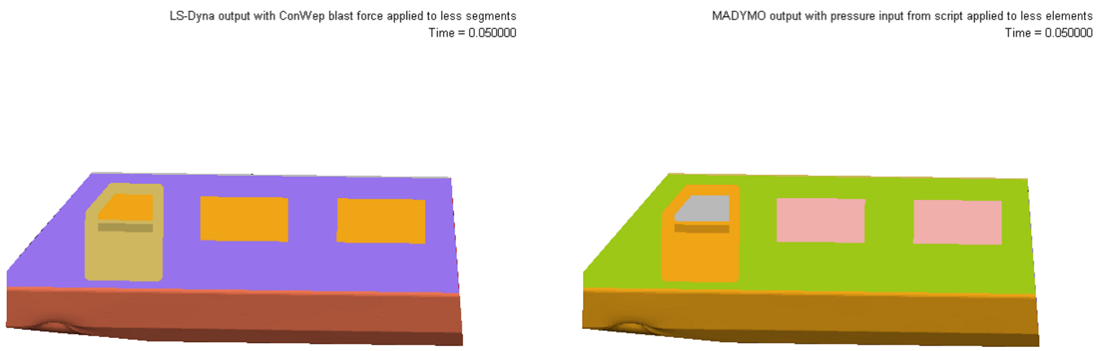


Figure 5.5 LS-Dyna output with ConWep blast force applied to fewer segments, and MADYMO output with pressure from script applied to fewer elements

The deformation and jump of the vehicle are less in models where pressure is applied to fewer elements than in the models where the force or pressure are applied to more segments/elements. Less segments/elements were chosen for use with the script which produces the pressure input for MADYMO because of time limitations of running the script.

Section 6: Conclusions

- Three full blast event simulation models with varying degrees of complexity and different loading methods were built in MADYMO.
- The simplest model, using planes, can be used to capture sub-events of vehicle rigid body response and occupant response during blast-off and slam-down. The occupant response captured by this model is due to acceleration of the vehicle and occupant contact with vehicle interior structures, and seat and restraint systems.
- The slightly more complex facet model can do the same things, and add potential partial or full rollover response of vehicle and occupant. Forces due to contact of the vehicle with the ground upon rollover can be captured.
- The rigid body models run very quickly, with CPU times of less than 15 minutes for the plane models and less than 2 hours for the facet model to run a 500msec simulation.
- The most complex model, using finite elements and facets, can be used to capture all sub-events, including hull floor and false floor deformation and its effect on occupant response. Using at least 8 CPUs, this model will run in less than 12 hours.
- It is important to exercise caution in how much FE content is included in the MADYMO simulations; at some point, the resulting models will no longer have the advantages of being fast-running and may take the same amount of time as the higher-fidelity LS-DYNA models.

Section 7: Recommendations

Depending on whether hull and floor deformation and vehicle rollover are critical to an analysis, and how much time is available for the analysis turnaround, the MADYMO model to use should be chosen. For a given charge mass and location, the effect of changes to the hull on the vehicle response and occupant response can be evaluated. For different charge masses and locations, the effects on vehicle and occupant responses can be evaluated. Design iterations can be performed in a time-efficient manner using MADYMO.

Future research in this area should include development and evaluation using more sophisticated loading methods in MADYMO such as the Particle Blast Method (from other projects such as Near Term Underbody Blast (NT-UBB) program), as well as adapting this methodology to specific ground vehicle programs and validate it against physical test results from LFT&E.

7.1: Technology Transition Opportunities & Drops

The MADYMO models and scripts developed in this project are available to any DoD agency or industry partner interested in performing similar rapid simulations of underbody blast scenarios (blastoff to return-to-ground) using the Commercial-Off-the-Shelf (COTS) tool MADYMO. Request for the same should be made to the UBM/T&E Program Manager, ARL/SLAD, Aberdeen, MD.

7.2: Payoffs

The following are some of the important payoffs from this project:

- For ARL/SLAD's mission needs, MADYMO is well-suited for rapid simulations using rigid body dynamics, where numerous scenarios can be quickly analyzed.
- MADYMO offers an alternative M&S method to using LS-DYNA for the entire blast event (from blastoff to slamdown); the latter is the subject of a different report.
- MADYMO offers the ability to create simple fast-running rigid body models which can describe the vehicle and loading to it, while at the same time, offering the ability to include occupant models (Hybrid-3) and assess injuries. Especially during the Analysis of Alternatives (AoA) and/or conceptual design phases, this is useful methodology for rapid M&S analyses.

Section 8: Disclaimer

Reference herein to any specific commercial company, product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Dept. of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the DoD, and shall not be used for advertising or product endorsement purposes.

Section 9: References/Bibliography

1. MADYMO User's Manual, Version 7.4, December 2011
2. Arepally, S., Gorsich, D., Hope, K., Gentner, S., and Drotleff, K., "Application of Mathematical Modeling in Potentially Survivable Blast Threats in Military Vehicles", 26th Army Science Conference, Orlando, FL, December 2008
3. Thyagarajan, R., "End-to-end System level M&S tool for Underbody Blast Events". 27th Army Science Conference, Army Technology Showcase, Orlando, FL, Nov 29 – Dec 2. DTIC Report # ADA550921, 2000
4. Tabiei, A., and Nilakantan, G., "Reduction of Acceleration Induced Injuries from Mine Blasts Under Infantry Vehicles", 6th European LS-DYNA Users' Conference, May 2007
5. Halquist, J.O., LS-DYNA Theory Manual, 2006
6. LS-DYNA Keyword User's Manual, Version 971/Rev 5, May 2010
7. Kingery, C., and Bulmarsh, G., "Airblast parameters from TNT Spherical Air Burst and Hemispherical Surface Burst," ARBRL-TR-02555, 1984
8. Final Report of HFM-090 Task Group 25, "Test Methodology for Protection of Vehicle Occupants against Anti-Vehicular Landmine Effects", NATO RTO TECHNICAL REPORT TR-HFM-090, April 2007
9. Ramalingam, J., and Thyagarajan, R., "Effects of Reclining Seat Positions on Blast Mitigation", Armor/Anti-Armor Threat Coordinating Group, NGIC Meeting #2784, Charlottesville, VA, July 2012. DTIC Report # ADB387221, 2013.
10. Thyagarajan, R., "Occupant Centric Protection (OCP) Technical Demonstrator (TECD): Current Occupant Protection Modeling and Simulation (M&S) Methods and Procedures Assessment and Baseline Version 1.0", DTIC Report # ADB387222, February 2013

Section 10: Appendices

Appendix A: List of files generated during the project

1. Model_Jump.xml
2. Model_Roll1.xml
3. Model_Roll2.xml
4. Blast_pressure_script_07.py
5. Model_plate_script_pres_unconstr.xml
6. Model_blast_pres_facet_upper_03_dummy.xml
7. MADfuncmod3.inc
8. MADloadpres3.inc
9. MADpresfunc3.inc
10. Plate_blast_02a_unconstrained.k
11. Plate_output.k
12. Plate_pressure.dyna
13. Facets_1_Actuator_2_Loc2.xml

Appendix B: Python script to convert pressure vs. time curves from LS-DYNA output file BLSTFOR to MADYMO input format

```
print ("The LS-Dyna keyword input file is:")
file1=input()
print ("The LS-Dyna keyword output file is:")
file2=input()
print ("The LS-Dyna blast force history file is:")
file3=input()
a=open(file1, 'r')
line=a.readline()
InputNodes={}
keycounter=1
while line:
    if line.rstrip('\n')=="*NODE":
        line=a.readline()
        while not line[0][0]=="*" and not line[0][0]=="$":
            key=str(keycounter)
            InputNodes[key]=line.rstrip('\n')
            keycounter=keycounter+1
            InputNodes[key]=InputNodes[key].split()
            for i in range(0,4):
                InputNodes[key][i]=float(InputNodes[key][i])
                InputNodes[key][i]=round(InputNodes[key][i],4)
            line=a.readline()
    line=a.readline()
a.close()
b=open(file2, 'r')
line=b.readline()
OrigOutputNodes={}
NewOutputNodes={}
keycounter=1
while line:
    if line.rstrip('\n')=="*NODE":
        line=b.readline()
        while not line[0][0]=="*":
            key=str(keycounter)
            OrigOutputNodes[key]=line.rstrip('\n')
            NewOutputNodes[key]=line.rstrip('\n')
            keycounter=keycounter+1
            OrigOutputNodes[key]=OrigOutputNodes[key].split()
            NewOutputNodes[key]=NewOutputNodes[key].split()
            for i in range (0,4):
                OrigOutputNodes[key][i]=float(OrigOutputNodes[key][i])

OrigOutputNodes[key][i]=round(OrigOutputNodes[key][i],4)
                NewOutputNodes[key][i]=float(NewOutputNodes[key][i])
                NewOutputNodes[key][i]=round(NewOutputNodes[key][i],4)
            line=b.readline()
    line=b.readline()
```

```
b.close()
b=open(file2, 'r')
line=b.readline()
OutputElements={}
NewOutputElements={}
keycounter=1
while line:
    if line.rstrip('\n')=="*ELEMENT_SHELL":
        line=b.readline()
        while not line[0][0]=="*" and not line[0][0]=="$":
            key=str(keycounter)
            OutputElements[key]=line.rstrip('\n')
            NewOutputElements[key]=line.rstrip('\n')
            keycounter=keycounter+1
            OutputElements[key]=OutputElements[key].split()
            NewOutputElements[key]=NewOutputElements[key].split()
            for i in range(0,6):
                OutputElements[key][i]=float(OutputElements[key][i])
                OutputElements[key][i]=round(OutputElements[key][i],4)

NewOutputElements[key][i]=float(NewOutputElements[key][i])

NewOutputElements[key][i]=round(NewOutputElements[key][i],4)
            line=b.readline()
    line=b.readline()
b.close()
for keycounter in range(1,len(InputNodes)+1):
    key=str(keycounter)
    for keycounter1 in range(1,len(InputNodes)+1):
        key1=str(keycounter1)
        if InputNodes[key1][1]==OrigOutputNodes[key][1] and
InputNodes[key1][2]==OrigOutputNodes[key][2] and
InputNodes[key1][3]==OrigOutputNodes[key][3]:
            NewOutputNodes[key][0]=InputNodes[key1][0]
            for keycounter2 in range(1,len(OutputElements)+1):
                key2=str(keycounter2)
                for i in range (2,6):
                    if
(OutputElements[key2][i]==OrigOutputNodes[key][0]):

NewOutputElements[key2][i]=NewOutputNodes[key][0]
a=open(file1, 'r')
line=a.readline()
InputElements={}
keycounter=1
while line:
    if line.rstrip('\n')=="*ELEMENT_SHELL":
        line=a.readline()
        while not line[0][0]=="*" and not line[0][0]=="$":
            key=str(keycounter)
            InputElements[key]=line.rstrip('\n')
            keycounter=keycounter+1
```

```
            InputElements[key]=InputElements[key].split()
            for i in range(0,6):
                InputElements[key][i]=float(InputElements[key][i])
                InputElements[key][i]=round(InputElements[key][i],4)
            line=a.readline()
    line=a.readline()
a.close()
c=open(file3, 'r')
line=c.readline()
BlastPressureOut={}
BlastPressureMAD={}
BlastPressureElem={}
MADin1=open("MADloadpres.inc","at")
MADin1.write('<?xml version="1.0"?>\n')
MADin1.write('<!DOCTYPE MADYMO_INCLUDE SYSTEM "mtd_3d.dtd">\n')
MADin1.write("<MADYMO_INCLUDE\n")
MADin1.write('  RELEASE="R7.4"\n')
MADin1.write("  >\n")
MADin1.close()
MADin2=open("MADpresfunc.inc","at")
MADin2.write('<?xml version="1.0"?>\n')
MADin2.write('<!DOCTYPE MADYMO_INCLUDE SYSTEM "mtd_3d.dtd">\n')
MADin2.write("<MADYMO_INCLUDE\n")
MADin2.write('  RELEASE="R7.4"\n')
MADin2.write("  >\n")
MADin2.close()
keycounter=1
while line:
    key=str(keycounter)
    BlastPressureOut[key]=line.rstrip('\n')
    BlastPressureOut[key]=BlastPressureOut[key].split()
    for entry in BlastPressureOut[key]:
        if entry.isdigit():
            for keycounter1 in range(1,len(NewOutputElements)+1):
                key1=str(keycounter1)
                for keycounter2 in range(1,len(InputElements)+1):
                    key2=str(keycounter2)
                    if
int(BlastPressureOut[key][0])==(NewOutputElements[key1][0]):
                        if
NewOutputElements[key1][2]==InputElements[key2][2] and
NewOutputElements[key1][3]==InputElements[key2][3] and
NewOutputElements[key1][4]==InputElements[key2][4] and
NewOutputElements[key1][5]==InputElements[key2][5]:

BlastPressureElem[key]=int(InputElements[key2][0])
                            ElemNum=str(BlastPressureElem[key])
                            MADin1=open("MADloadpres.inc","at")
                            MADin1.write("        <LOAD.PRES\n")
                            MADin1.write('            ELEMENT_LIST="')
                            MADin1.write(ElemNum)
                            MADin1.write('"\n')
```

```
                            MADin1.write('
PRES_FUNC="/pres')
                            MADin1.write(ElemNum)
                            MADin1.write('"\n')
                            MADin1.write("         />\n")
                            MADin1.close()
            line=c.readline()
            line=c.readline()
            line=c.readline()
            MADin2=open("MADpresfunc.inc","at")
            MADin2.write("   <FUNCTION.XY\n")
            MADin2.write('      ID="')
            MADin2.write("100")
            MADin2.write(ElemNum)
            MADin2.write('"\n')
            MADin2.write('      NAME="pres')
            MADin2.write(ElemNum)
            MADin2.write('"\n')
            MADin2.write("      >\n")
            MADin2.write("      <TABLE\n")
            MADin2.write('         TYPE="XY_PAIR"\n')
            MADin2.write("         >\n")
            MADin2.write("<![CDATA[\n")
            MADin2.write("|      XI                  YI
|\n")
            MADin2.close()
            while not line[0][0]=="e":
                BlastPressureMAD[key1]=line.rstrip('\n')
                line=c.readline()
                MADin2=open("MADpresfunc.inc","at")
                MADin2.write(BlastPressureMAD[key1])
                MADin2.write("\n")
                MADin2.close()
                keycounter=keycounter+1
            MADin2=open("MADpresfunc.inc","at")
            MADin2.write("]]>")
            MADin2.write("     </TABLE>\n")
            MADin2.write("   </FUNCTION.XY>\n")
            MADin2.close()
    line=c.readline()
c.close()
MADin1=open("MADloadpres.inc","at")
MADin1.write("</MADYMO_INCLUDE>")
MADin1.close()
MADin2=open("MADpresfunc.inc","at")
MADin2.write("</MADYMO_INCLUDE>")
MADin2.close()
```

Section 11: Distribution List

- Mr. Sudhakar Arepally, Associate Director, Analytics, US Army TARDEC
- Mr. Craig Barker, SLAD, US Army Research Labs
- Mr. Ross Boelke, OCP-TECD PM, TARDEC/GSS
- Mr. Chuck Coutteau, Deputy Executive Director, GSEAA, US Army TARDEC
- Dr. Kent Danielson, Engineer Research and Development Center (ERDC), Army Core of Engineers
- Mr. Paul Decker, Deputy Chief Scientist, US Army TARDEC
- Mr. Matt Donohue, DASA/R&T, ASA-ALT
- Ms. Nora Eldredge, WMRD, US Army Research Labs
- Mr. Ed Fioravante, WMRD, US Army Research Labs
- Mr. Ami Frydman, WMRD, US Army Research Labs
- Mr. Neil Gniazdowski, WMRD, US Army Research Labs
- Dr. David Gorsich, Chief Scientist, US Army TARDEC
- Mr. Pat Horton, Program Manager, UBM/T&E, SLAD, US Army Research Labs
- Mr. Jeff Jaster, Depurt Associate Director, TARDEC/GSS
- Dr. Steve Knott, Associate Director, TARDEC/GSS, US Army TARDEC
- Mr. Dick Koffinke, Survivability Directorate, US Army Evaluation Center
- Dr. Scott Kukuck, PM/Blast Institute, WMRD, US Army Research Labs
- Dr. David Lamb, STE/Analytics, US Army TARDEC
- Dr. Tom McGrath, US Navy NSWC-IHD
- Mr. Kirk Miller, OCP-TECD Standards and Specifications, TARDEC/GSS
- Mr. Micheal O'Neil, MARCOR SYSCOM, USMC
- Ms. Regina Rogers, OCP-TECD Deputy PM, TARDEC/GSS
- Mr. Ed Sievika, NAVAIR
- Mr. Mark Simon, Survivability Directorate, US Army Evaluation Center
- Mr. Neeraj Shukla, SLAD, US Army Research Labs
- Dr. Doug Templeton, TARDEC/GSS
- Mr. Pat Thompson, US Army Testing and Evaluation Command (ATEC)
- Mr. Madan Vunnam, Team Leader, Analytics/EECS, US Army TARDEC
- TARDEC TIC (Technical Information Center) archives, US Army TARDEC